



# The North Pacific Summer Jet and Climate Extremes Over North America: Mechanisms and Model Biases

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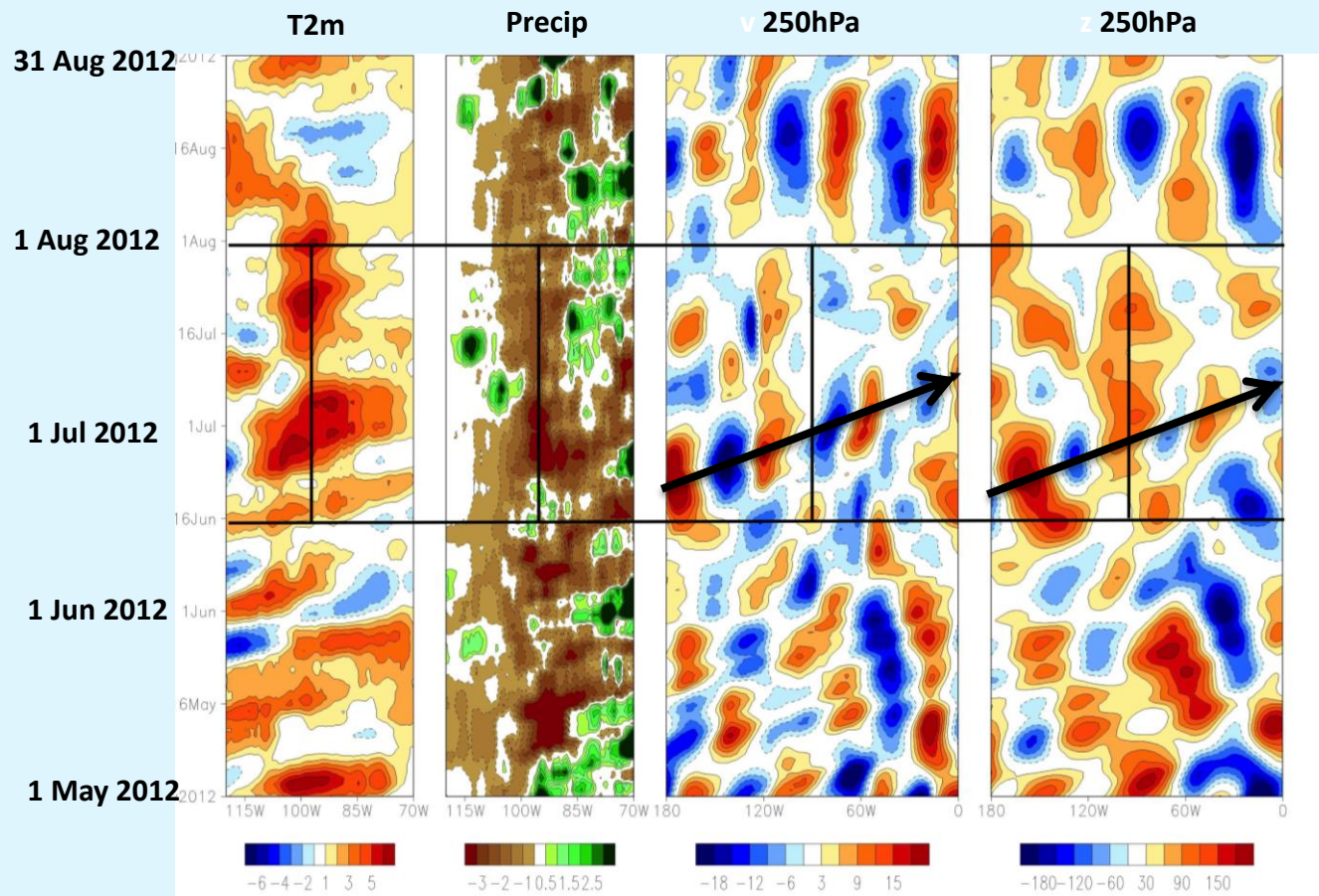
GC51F: Climate Extremes: Patterns, Mechanisms, and Attribution I

## North Pacific Summer Jet (NPSJ)

- Serves as a wave guide for Rossby waves (and other transients) that play a key role in *short term extremes*
- Influences directly or indirectly a host of processes that determine the mean climate over North America including the precipitation over the Great Plains



## Rossby waves linked to flash drought (2012 US Great Plains, 34°N-46°N)



Wang, H., S. Schubert, R. Koster, Y. Ham, and M. Suarez, 2014: On the Role of SST Forcing in the 2011 and 2012 Extreme U.S. Heat and Drought: A Study in Contrasts. *J. Hydrometeor.*, 15, 1255–1273, <https://doi.org/10.1175/JHM-D-13-069.1>

## The GEOS-5 AGCM\* (like many models) has until recently had significant biases in the NPSJ

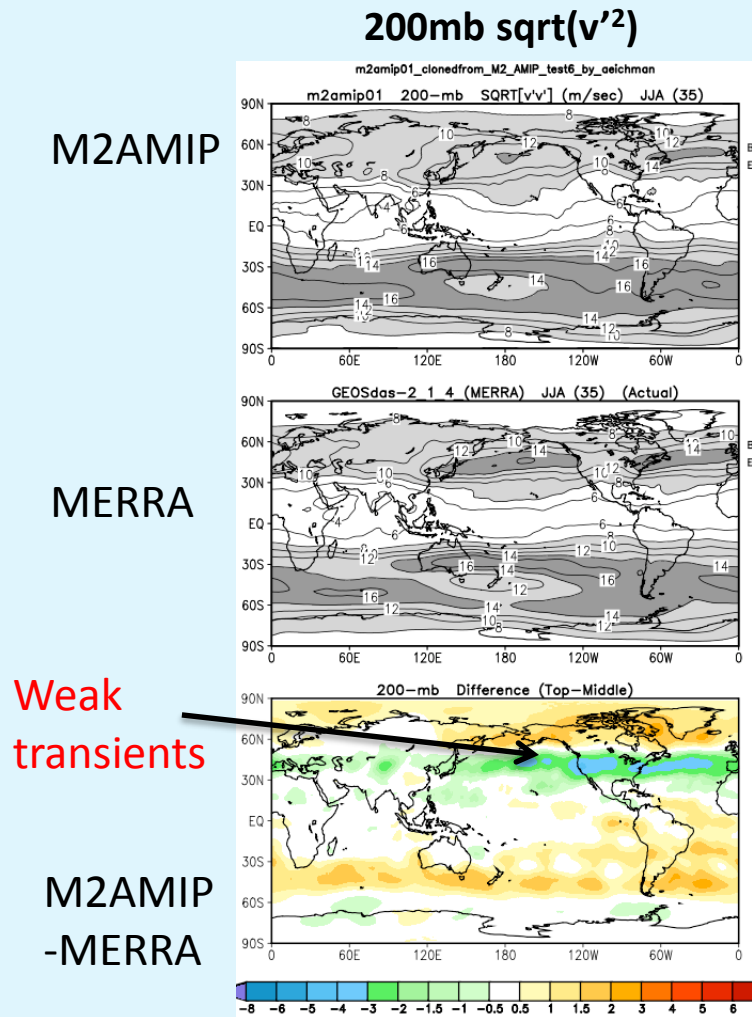
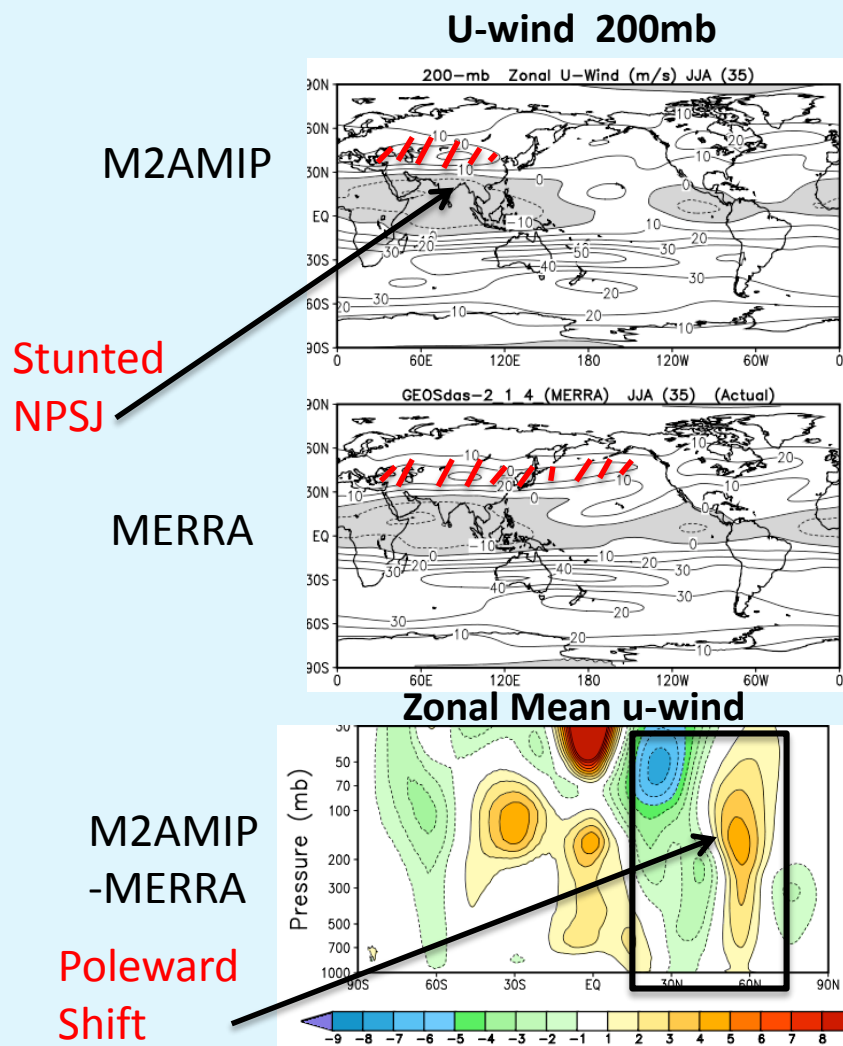
The biases appear to have two components:

- a stunted jet with maximum winds confined to the Asian continent
- a zonally-symmetric poleward shift

Associated with those NPSJ biases are weak and poleward-shifted middle latitude transients and a dry bias over the US Great Plains

\*Molod, A., L. Takacs, M. Suarez, and J. Backmeister, 2015: Development of the GEOS-5 atmospheric general circulation model: evolution from MERRA to MERRA2. *Geosci. Model Dev.*, **8**, 1339-1356, doi: 10.5194/gmd-8-1339-2015.

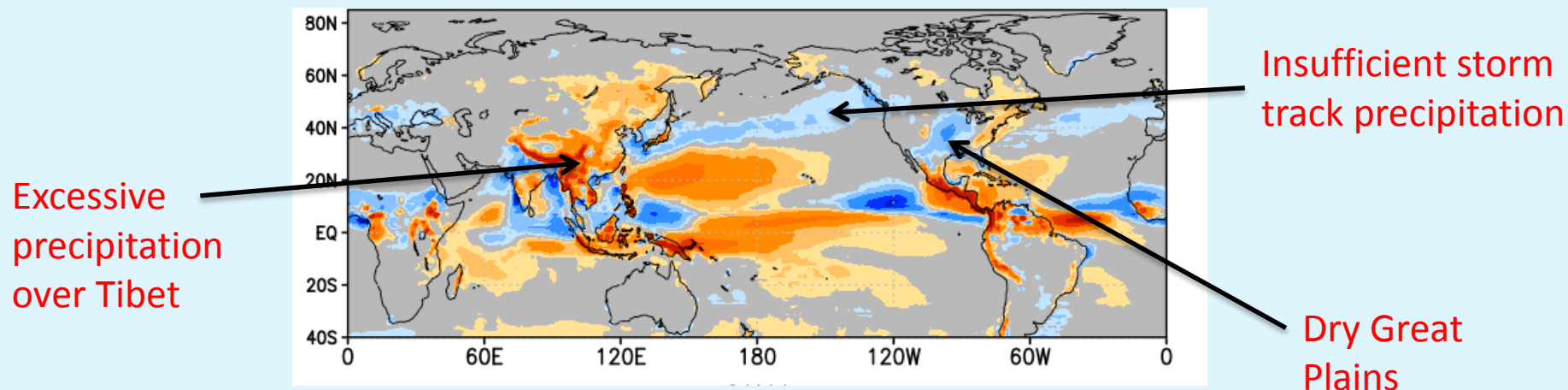
# Example of JJA Biases: AGCM that was used to produce MERRA-2



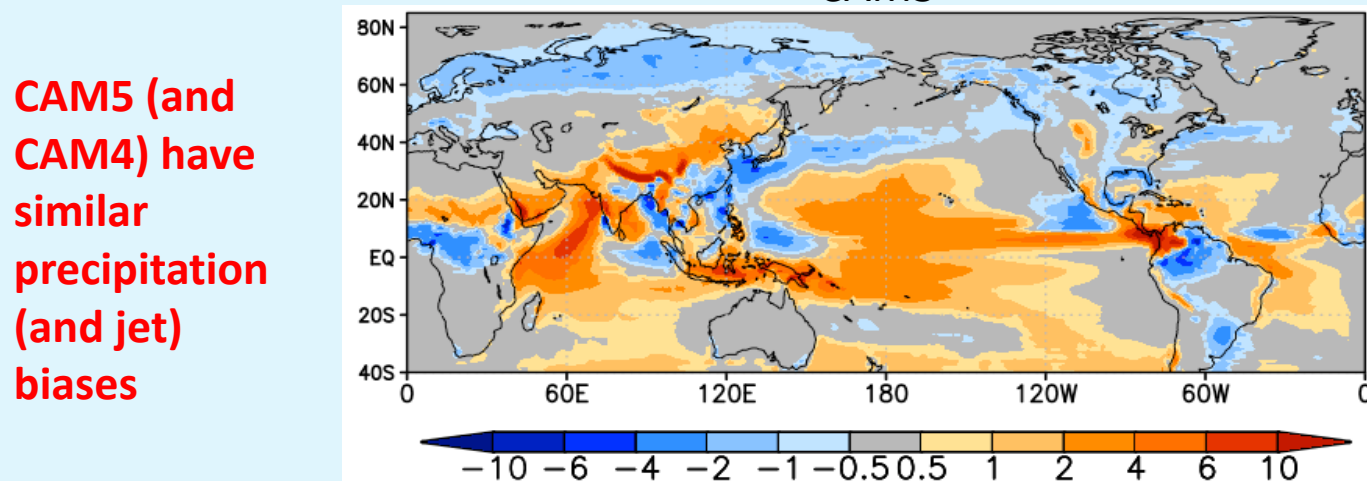


## JJA Precipitation Bias wrt GPCP

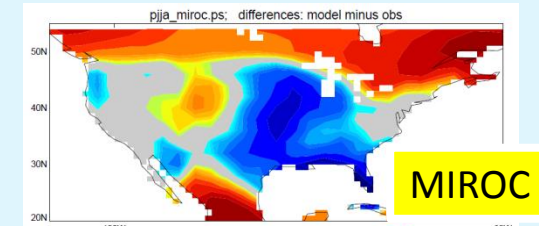
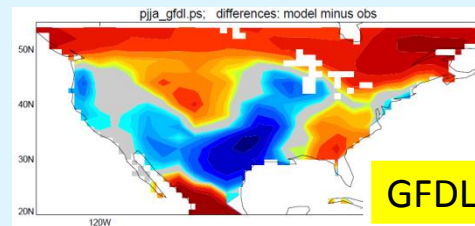
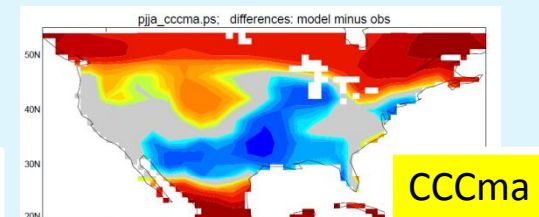
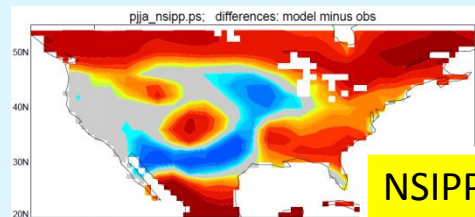
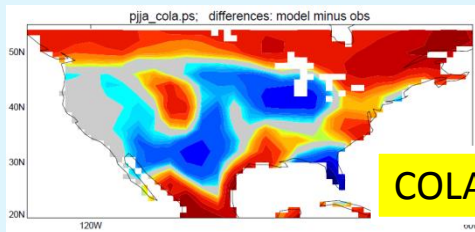
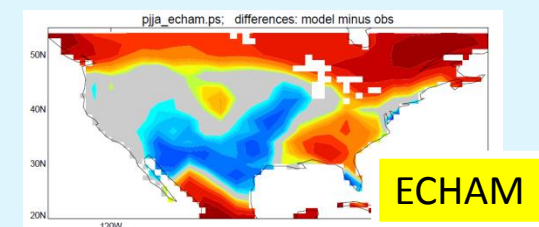
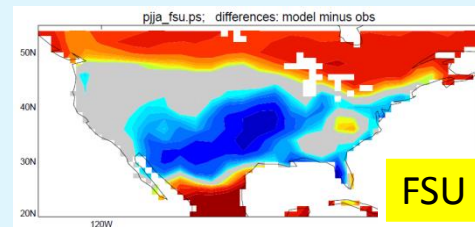
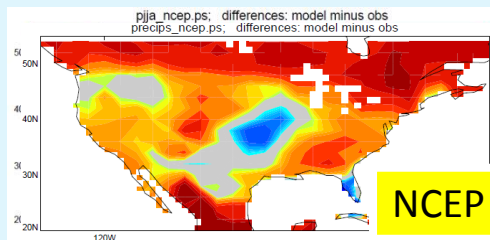
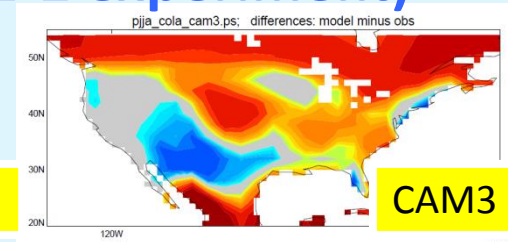
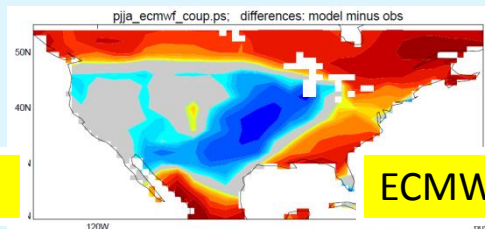
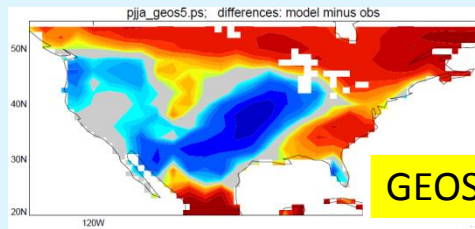
GEOS-5 M2AMIP



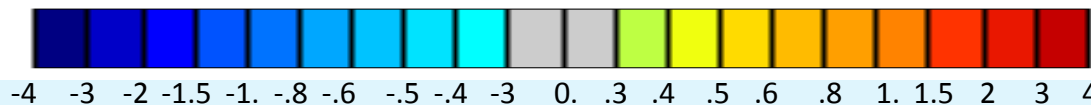
CAM5



## JJA Precipitation (from GLACE-2 experiment)



(Note: ignore differences in Canada and Mexico; they stem from U.S.-only precipitation observations.)



Koster et al. 1/2013



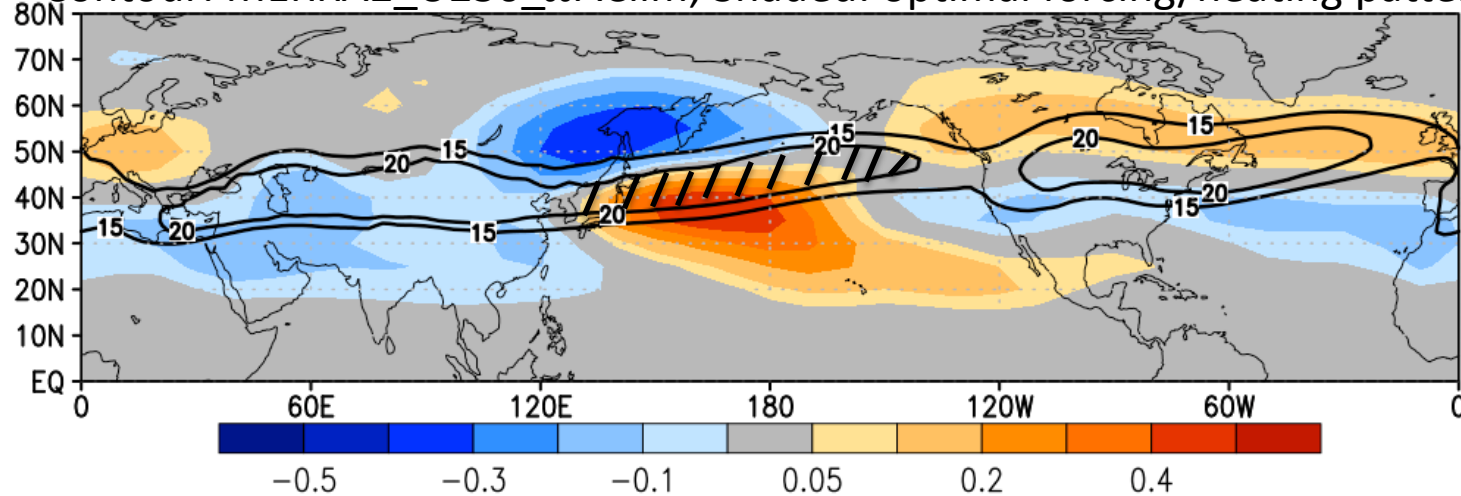
# Is there a link between the precipitation biases and NPSJ biases?

## Stationary Wave Model Experiments (SWM)

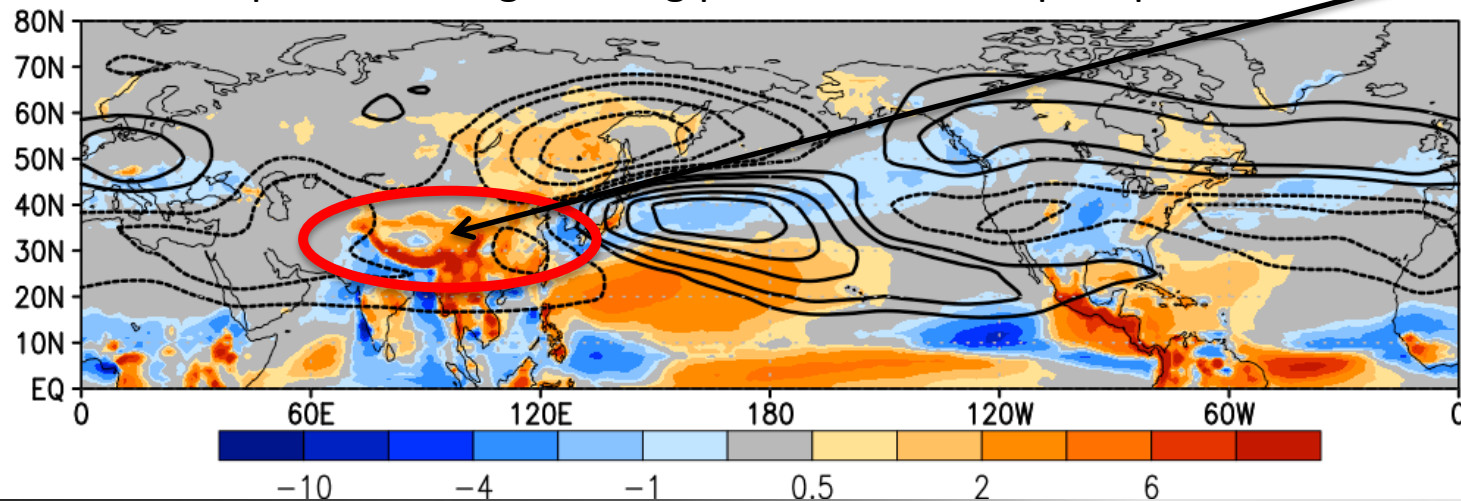
- SWM described in Ting and Yu (1998)
  - 3-dimensional primitive equations (R30L14)
- Performed a set of idealized SWM experiments forced with idealized latent heating anomalies characterized by:
  - $20^{\circ}\text{lat}$  by  $40^{\circ}\text{lon}$ ; peak in the middle troposphere, placed every  $10^{\circ}$  longitude and  $5^{\circ}$  latitude
- *Produced a “**sensitivity map**”: essentially an approximation (within the SWM framework) of the Green’s function of the atmospheric response to heating (e.g., Branstator 1985; Barsugli and Sardeshmukh 2002)*

## Optimal forcing pattern for enhancing the NPSJ (hatched area)

Contour: MERRA2\_U250\_JJAClim; Shaded: optimal forcing/heating pattern



Contour: optimal forcing/heating pattern; Shaded: precip bias in M2AMIP



**Excessive heating over Tibet suppresses the jet**

## How have recent GEOS model developments impacted these biases? (Cloud Microphysics\* and Vertical Resolution)

Examine a suite of 1 deg AGCM runs

**A:** 72 levels, 1-moment ~M2AMIP

**B:** 72 levels, 2-moment

**C:** 132 levels, 1-moment

**D:** 132 levels, 2-moment

$$((B-A) + (D - C))/2.0$$

**1m->2m**

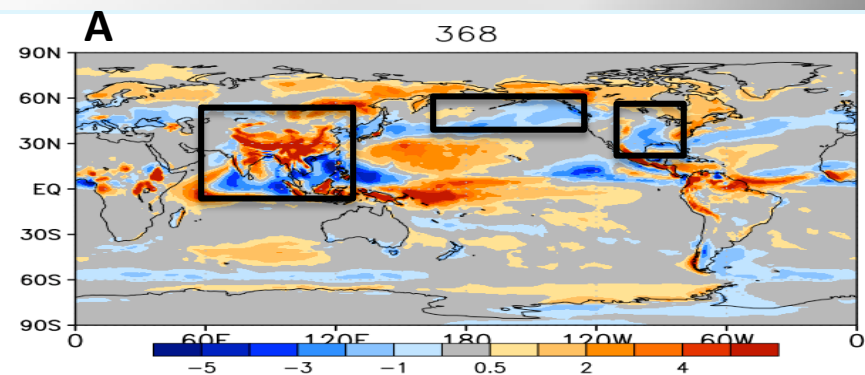
**impact of microphysics**

$$((C - A) + (D - B))/2.0$$

**72->132lev**

**Impact of increased vertical res**

\*Barahona, D., A. Molod, J. Bacmeister, A. Nenes, A. Gettelman, H. Morrison, V. Phillips, and A. Eichmann, 2014. Development of two-moment cloud microphysics for liquid and ice within the NASA Goddard Earth Observing System Model (GEOS-5). *Geosci. Model Dev*, 7, 1733-1766. doi: 10.5194/gmd-7-1733-2014.

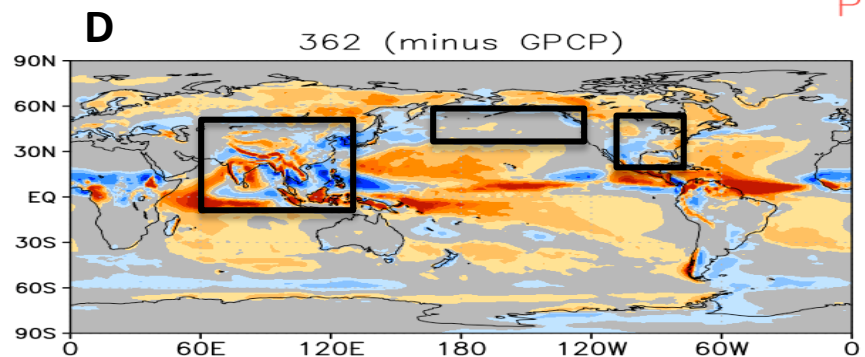


**JJA  
Precipitation  
Biases**

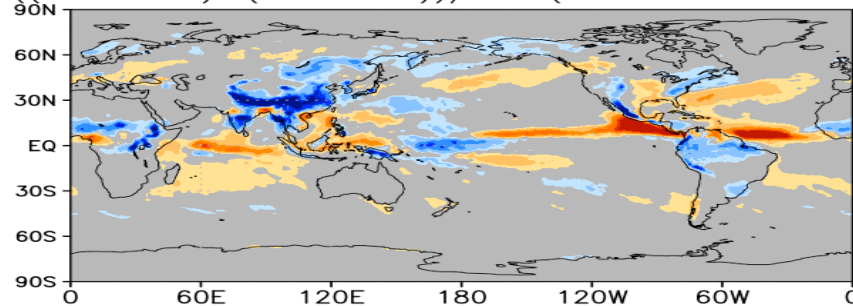
**Impact of  
Microphysics**

**+**

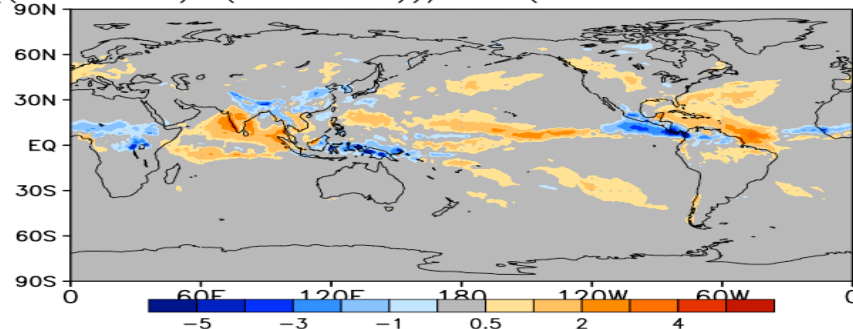
**Impact of  
Vertical  
resolution**



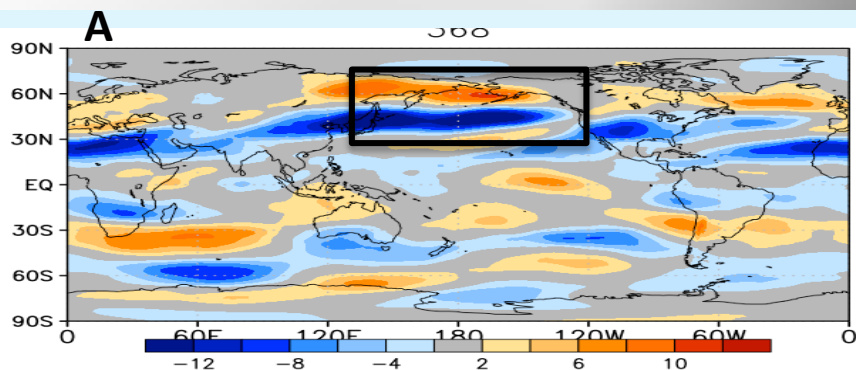
$((363-368)+(362-361))/2.0$  (effect of 1m  $\rightarrow$  2m)



$((361-368)+(362-363))/2.0$  (effect of 72  $\rightarrow$  132lev)



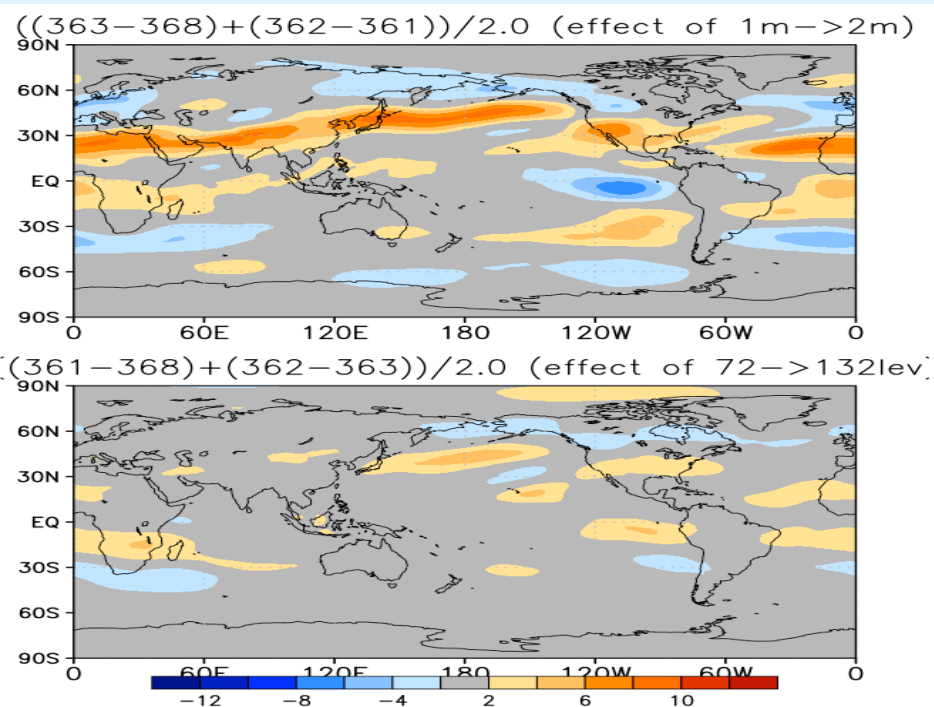
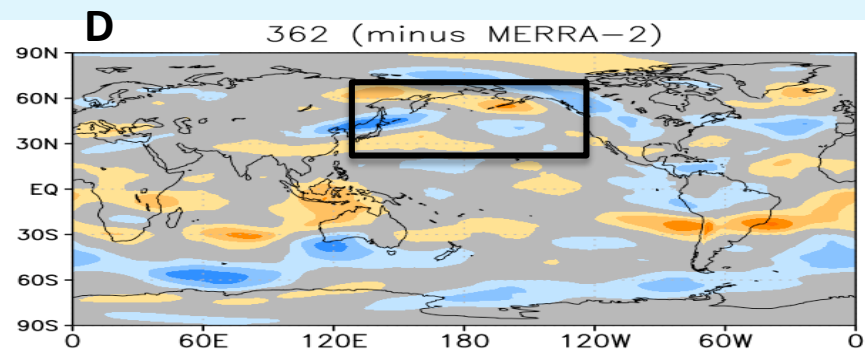
**Substantial improvements  
in several key areas  
primarily from microphysics**



JJA 250mb  
u-wind  
Biases

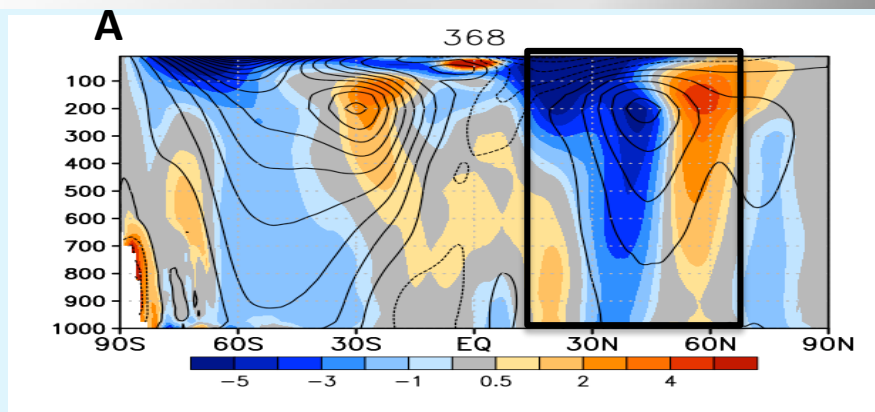


Impact of  
Microphysics  
+  
Impact of  
Vertical  
resolution



Substantial improvements in u-  
250mb primarily from  
microphysics



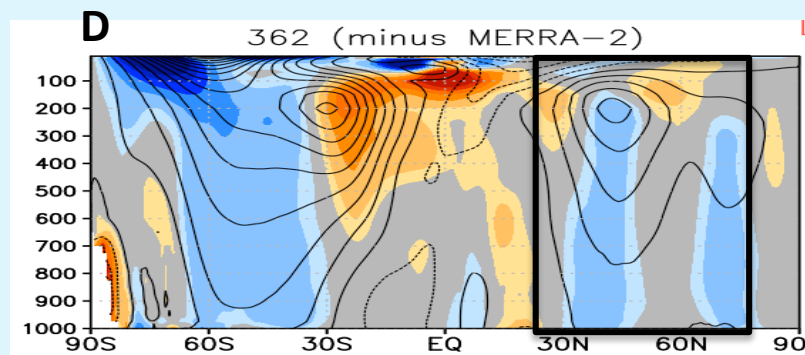


JJA zonal  
mean u-wind  
Biases

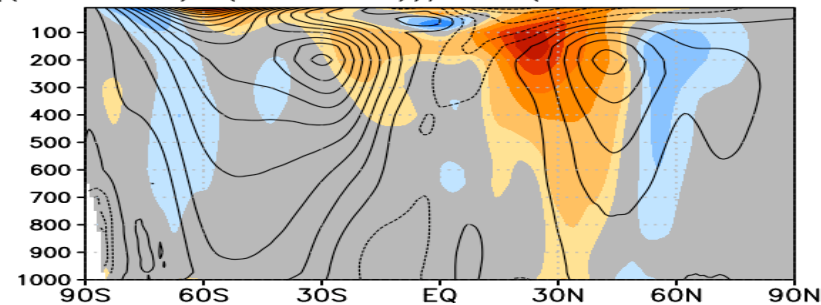
Impact of  
Microphysics

+

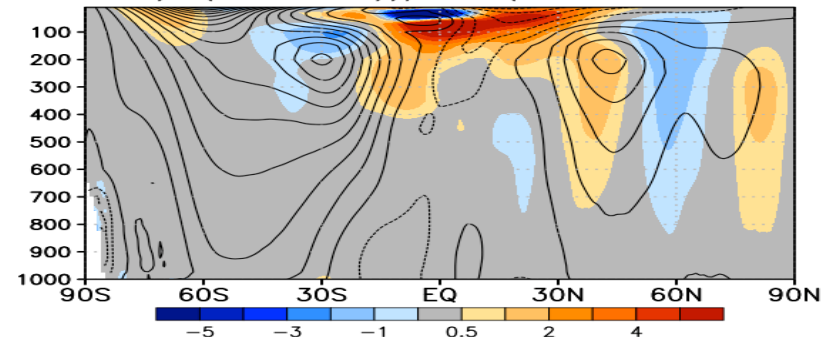
Impact of  
Vertical  
resolution



$((363-368)+(362-361))/2.0$  (effect of 1m->2)



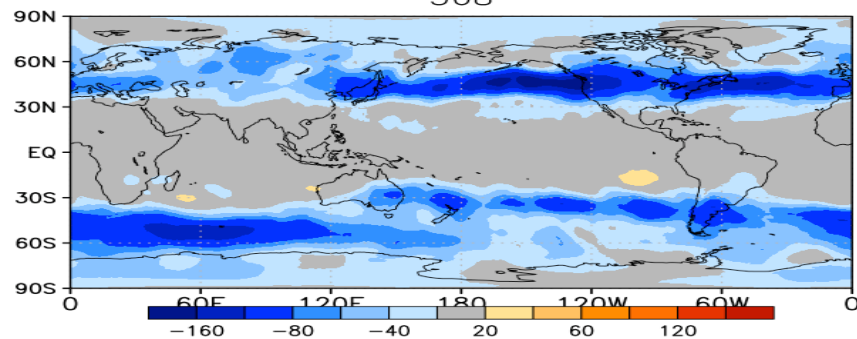
$(361-368)+(362-363))/2.0$  (effect of 72->132)



Substantial improvements in zonal  
mean u-wind from both  
microphysics and vertical resolution

A

368



JJA 250mb  
 $v'^2$  Biases



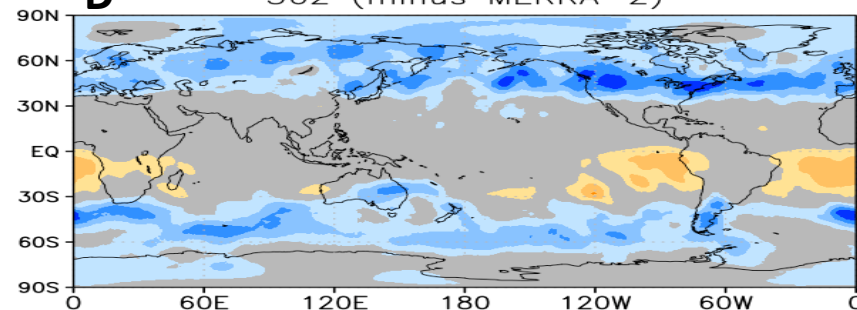
Impact of  
Microphysics

+

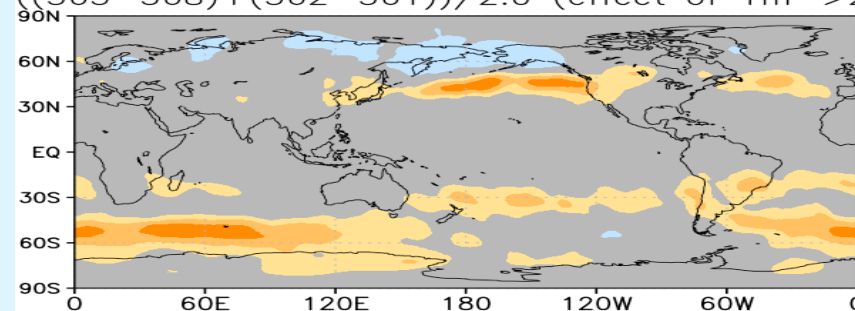
Impact of  
Vertical  
resolution

D

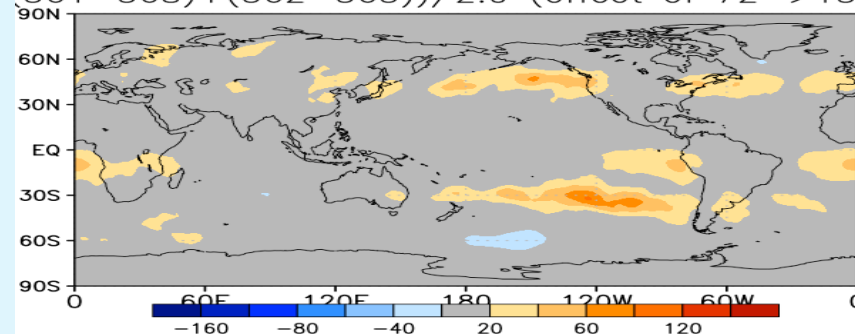
362 (minus MERRA-2)



$((363-368)+(362-361))/2.0$  (effect of 1m  $\rightarrow$  2m)

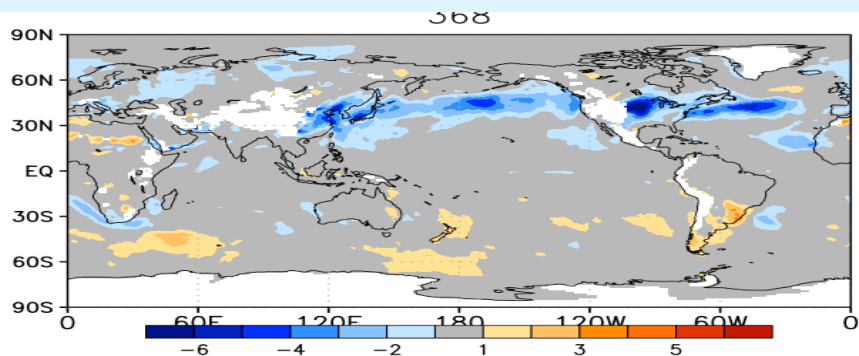


$(361-368)+(362-363))/2.0$  (effect of 72  $\rightarrow$  132lev)



Substantial improvements in  
250mb  $v'^2$  from both microphysics  
and vertical resolution

A



JJA 850mb  
v'q' Biases

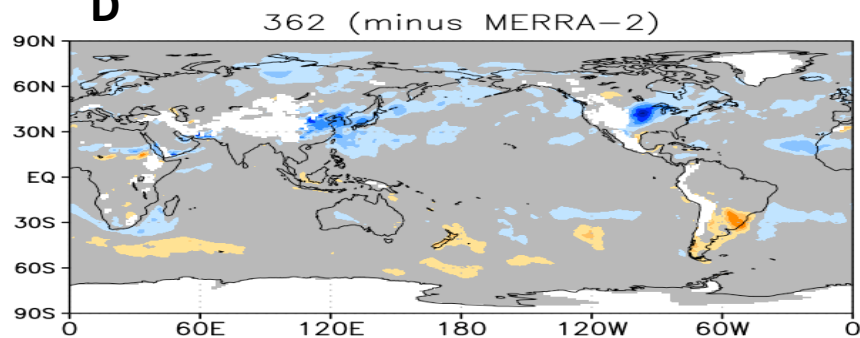
Impact of  
Microphysics

+

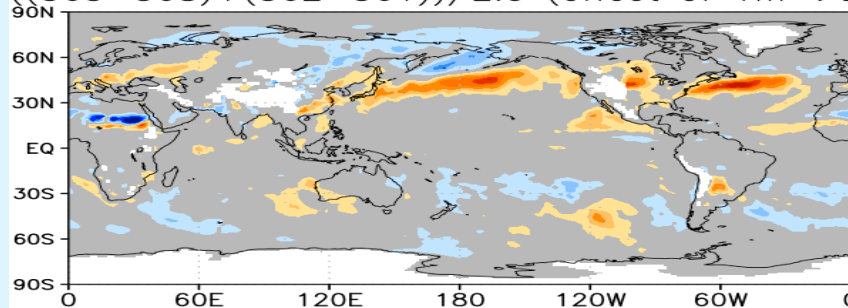
Impact of  
Vertical  
resolution



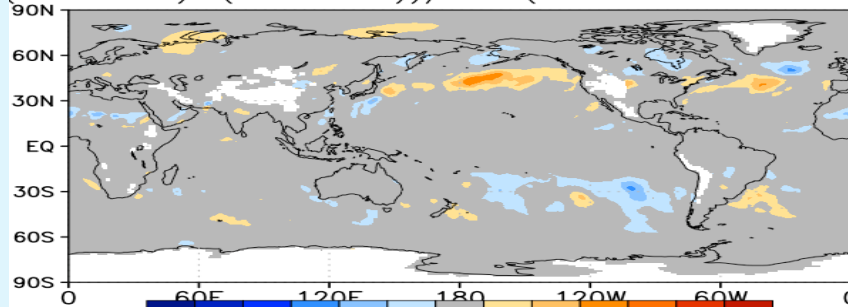
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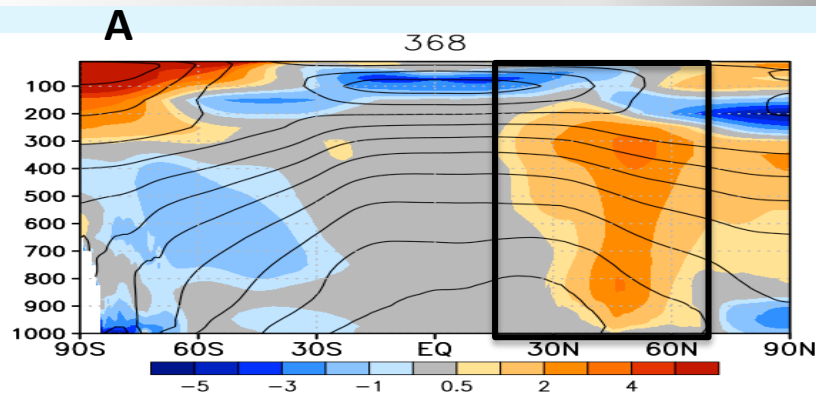
$((363-368)+(362-361))/2.0$  (effect of 1m→2m)



$(361-368)+(362-363))/2.0$  (effect of 72→132lev)



Substantial improvements in 850mb  
v'q' from both microphysics and  
vertical resolution

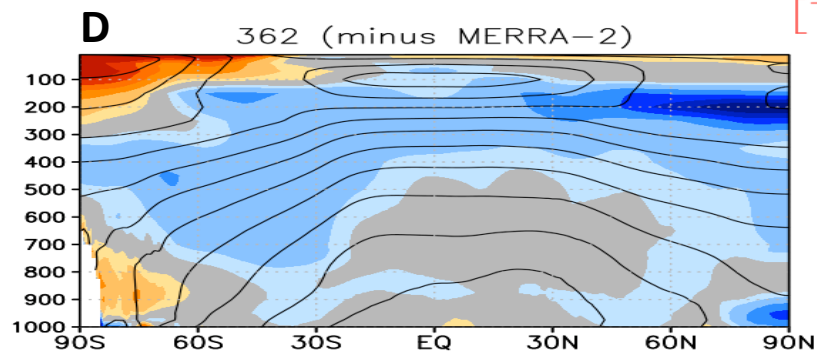


JJA zonal mean  
T Biases

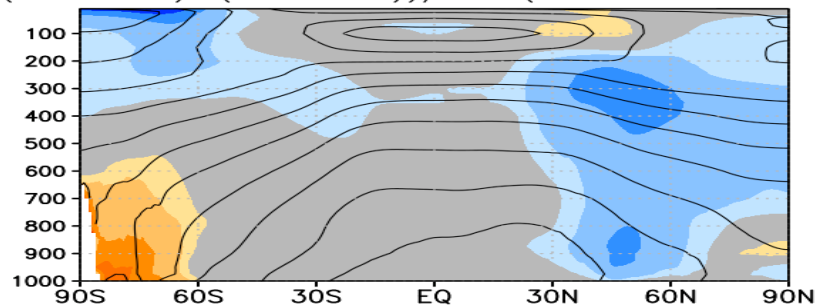
Impact of  
Microphysics

+

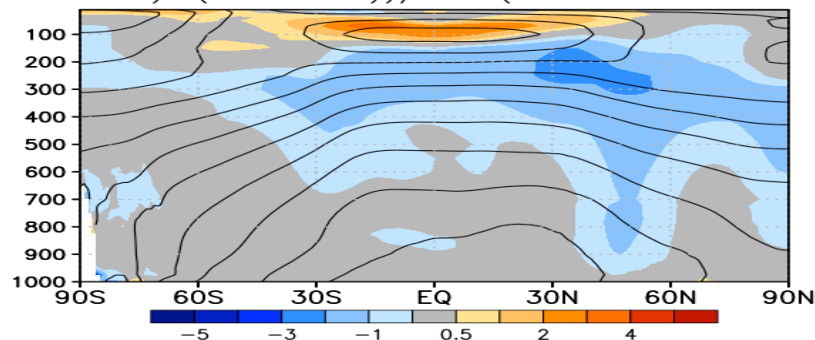
Impact of  
Vertical  
resolution



$((363-368)+(362-361))/2.0$  (effect of 1m  $\rightarrow$  21



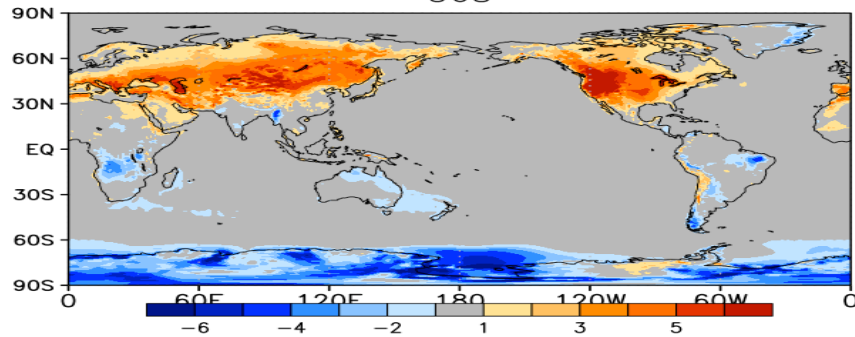
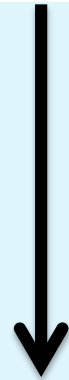
$((361-368)+(362-363))/2.0$  (effect of 72  $\rightarrow$  132



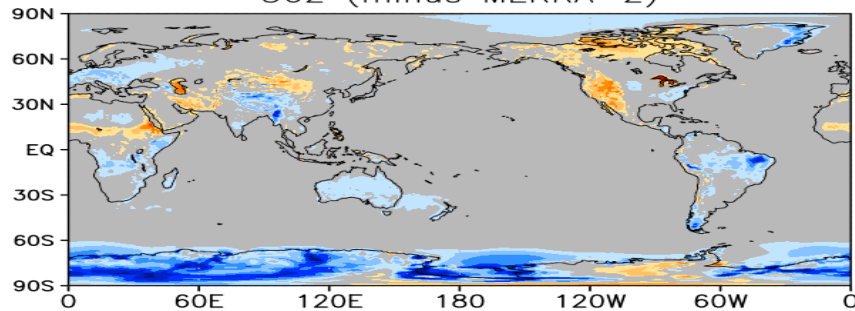
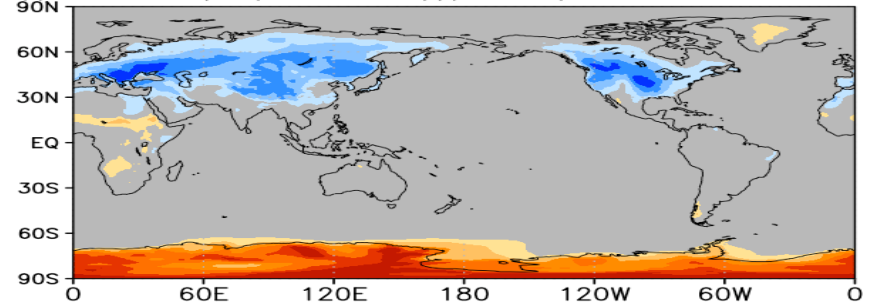
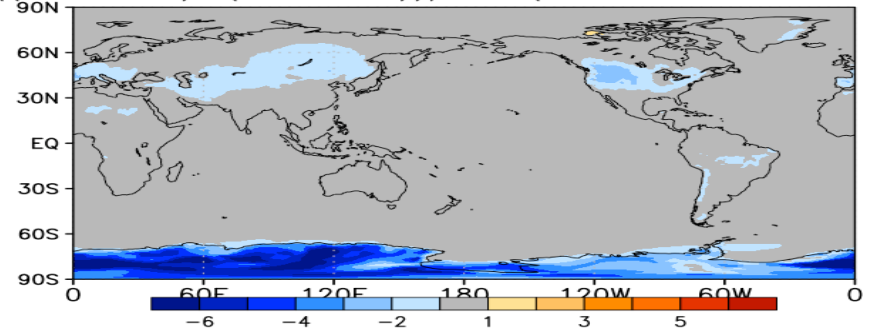
Substantial improvements in zonal  
mean T from both microphysics and  
vertical resolution

**A**

368

**JJA T2m  
Biases****Impact of  
Microphysics****+****Impact of  
Vertical  
resolution****D**

362 (minus MERRA-2)

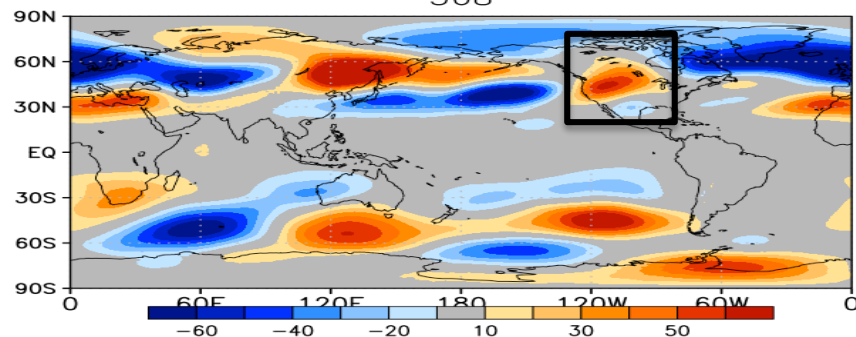
**2m** $((363-368)+(362-361))/2.0$  (effect of 1m→2m) $((361-368)+(362-363))/2.0$  (effect of 72→132lev)

Substantial improvements in T2m  
from both microphysics and  
vertical resolution



A

368



JJA 250mb  
eddy height  
Biases

Impact of  
Microphysics

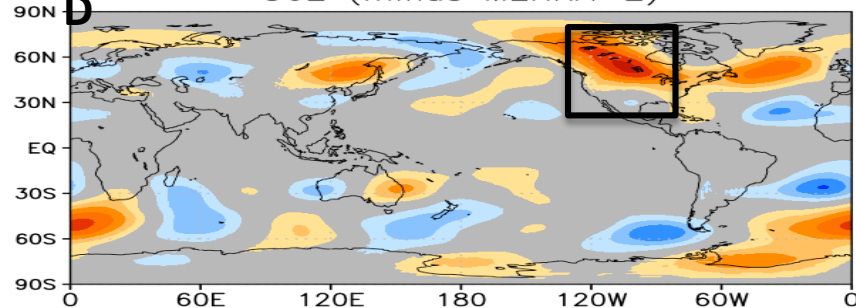
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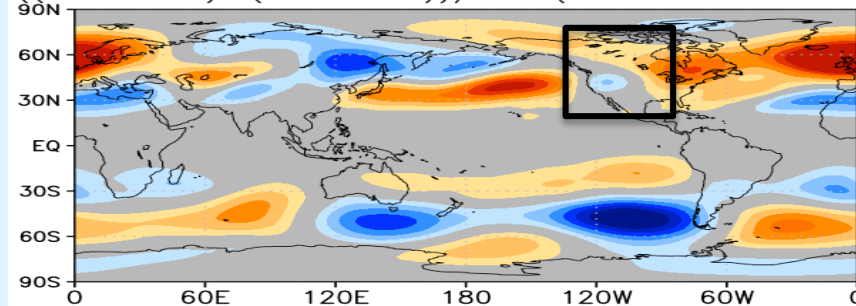
Impact of  
Vertical  
resolution

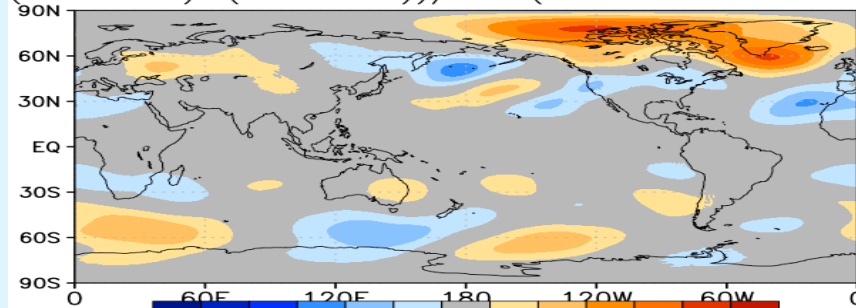


D

362 (minus MERRA-2)

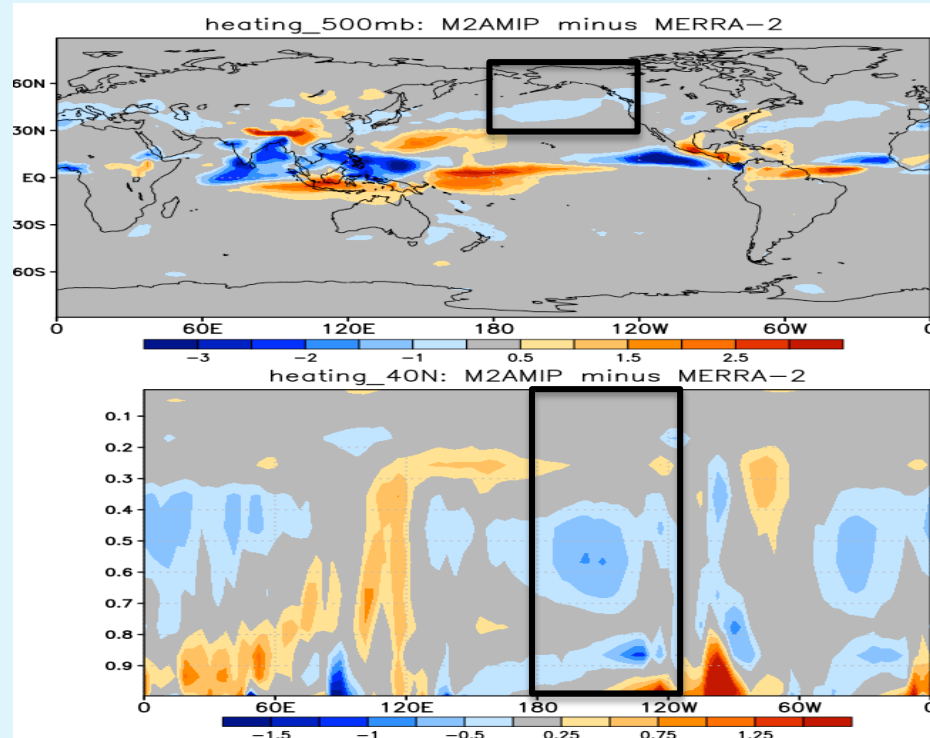


$$((363-368)+(362-361))/2.0 \text{ (effect of } 1\text{m} \rightarrow 2\text{m)}$$


$$(361-368)+(362-363))/2.0 \text{ (effect of } 72 \rightarrow 132 \text{ lev)}$$


Overall improvements in eddy  
250mb height, but little change  
over North America

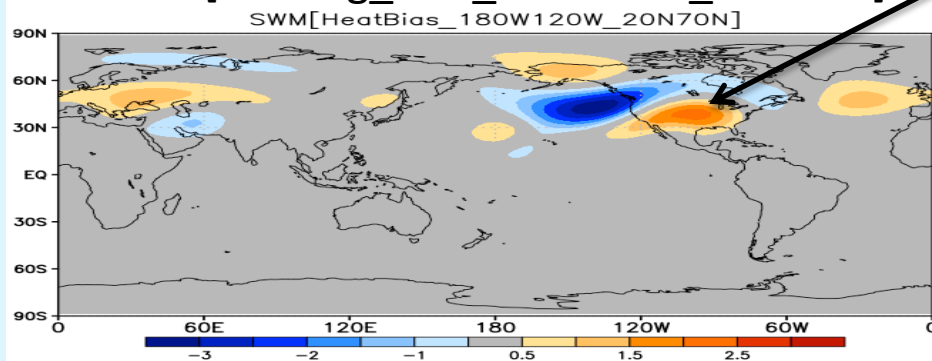
## JJAClim Heating: M2AMIP minus MERRA-2



500mb

35N-50N mean

**SWM[Heating\_Bias\_180E120E\_20N70N]**



**Negative M2AMIP heating/precipitation anomalies over northeast Pacific (see above region) produce an anomalous high over US in the SWM**

## Summary

- The NPSJ serves as a critical conduit for transients that impact the climate (including extremes) over North America
- The GEOS-5 AGCM has, until recently, had a deficient NPSJ that was both stunted and shifted poleward, problems that seem to be common to many other AGCMs
- These NPSJ deficiencies appear to be associated with a number other model deficiencies including weak transients, a dry bias in the US Great Plains and an overall surface warming bias over much of the middle latitude land areas
- The introduction of 2-moment cloud microphysics results in substantial improvement to the NPSJ and many related aspects of the boreal summer climate: apparently primarily by reducing the precipitation bias over Tibet
- Vertical resolution also helps mainly by ameliorating the poleward shift of the jet
- The physical mechanisms by which the changes in cloud microphysics and vertical resolution lead to these improvements is currently under investigation

## Implications for further work on North American climate variability and extremes

- revisit the link between Asia/Tibet and North American summer climate focusing on the forcing and role of the NPSJ  
e.g., Ding and Wang, 2005: Circumglobal Teleconnections in the Northern Hemisphere, J. Climate 2005 18:17, 3483-3505
- examine whether poleward shifts in the boreal summer jet that occur in nature are linked to hemispheric-wide drought and/or surface warming
- examine whether (and at what time scales) variability in the heating in the Northeast Pacific (perhaps linked to variability in the NPSJ) is an important factor contributing to the summer variability of the North American ridge and drought